NASA's Space Environments and Effects (SEE) Program

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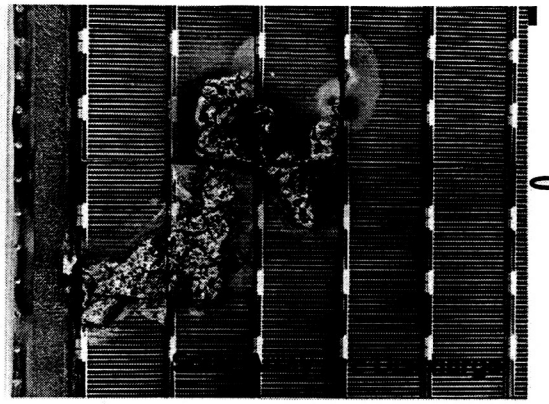
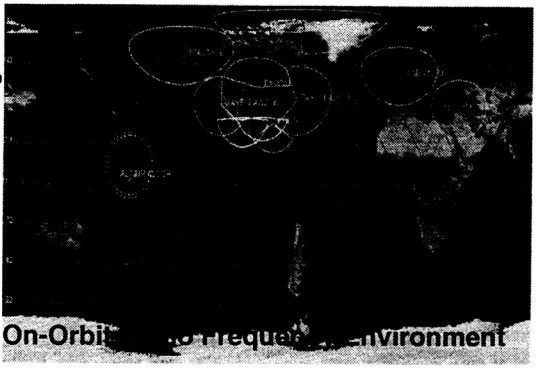
Value of the SEE Program
Issues to be Resolved:

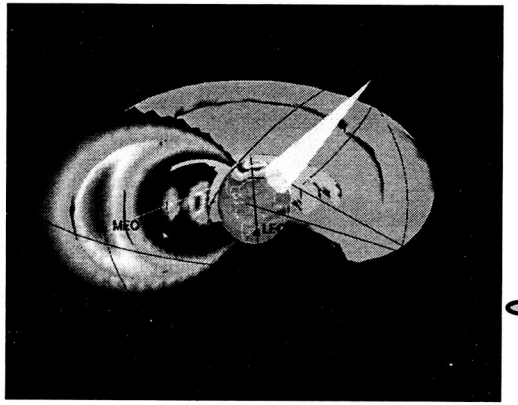


Solar array arcing can cripple satellites and their power systems.

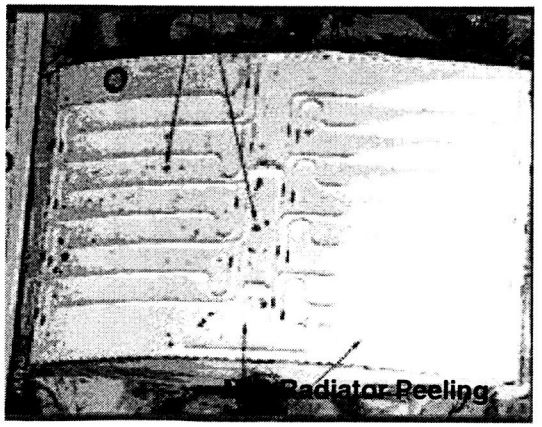
Electromagnetic interference is a constant threat to every satellite.



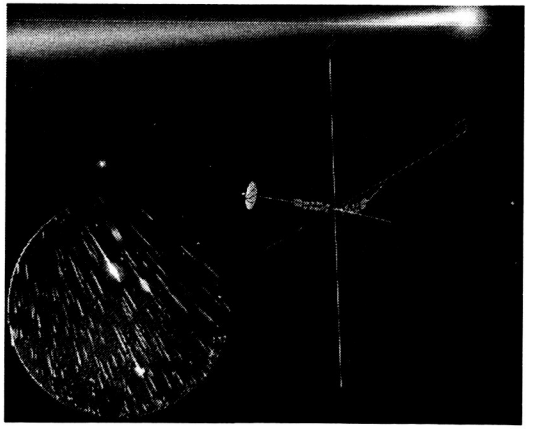
On-orbit materials can degrade and erode causing satellite damage.

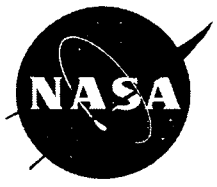


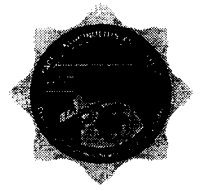
Electronic parts are extremely susceptible to radiation damage.



Membrane structures will be susceptible to meteoroid impacts and impact induced plasma charging.



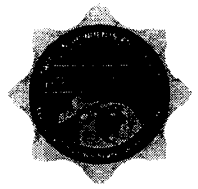




SEE Program Description

- Space Environments & Effects (SEE) Program - Agency-wide program designed to help spacecraft and spacecraft systems mitigate the harmful effects of the different space environments:
  - Ionizing Radiation
  - Electromagnetic Effects
  - Spacecraft Charging
  - Materials & Processes
  - Meteoroids & Orbital Debris
  - Neutral External Contamination

- Advocate technology development, flight experiments, and databases by developing and maintaining:
  - Environments Definitions and Handbooks
  - Engineering Design Guidelines and Handbooks
  - Integrated Engineering Assessment Models
  - Environments and Materials Databases
  - Flight/Ground Simulation/Technology Assessment Data



SEE Program Description

- Maintain cutting-edge expertise in SEE-related technologies
  - Collaboration of NASA and Non-NASA technical experts/specialists
  - Sustained awareness of state-of-the-art SEE technologies

- SEE Program funds technology development activities either by NASA Research Announcements (NRAs), other solicitations, or direct funding from the SEE Program

- SEE Program ensures that these products are disseminated to the engineering community for use in spacecraft designs early in design process

  - Examples: Orbital Space Plane is base-lining 3 environment models sponsored by SEE
    JIMO will be utilizing a new meteoroid model sponsored by SEE
    JWST is utilizing a L2 & meteoroid environment model sponsored by SEE

Cooperative Efforts

Partnerships

NASA
MSFC
GSFC
JPL
LaRC
GRC
JSC
HQ

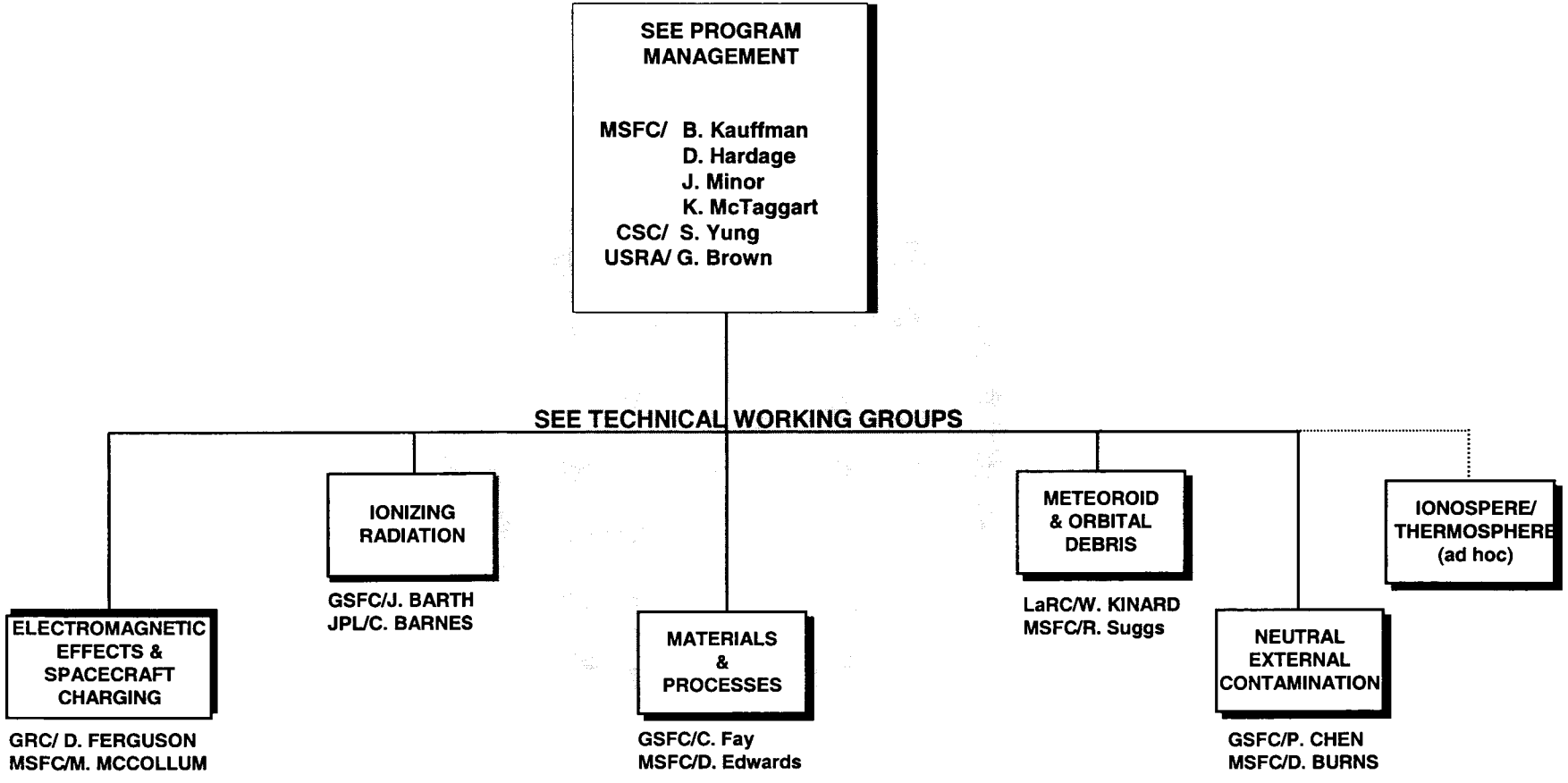
Government
AFRL- Hanscom
AFRL- WPAFB
AFRL – Edwards AFB
NRL
European Space Agency
NAVSEA

Industry
BWACS
SAIC
Physical Sciences, Inc.
AZ Technology, Inc.
CAT Flight Services
Longhill Engineering
Sverdrup

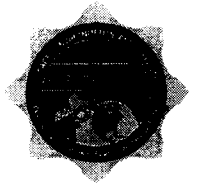
Customers
NASA Enterprises
MSFC Directorates
Other Government
US Industry
Academia

Academia
Utah State University
University of Western Ontario
USRA
Clemson University

SEE Program Organization



SEE-LWS/SET NASA Research Announcement



- *Background:* Living With A Star (LWS)/Space Environments Testbed (SET) Project

  - Program to perform applications research on environment interactions with spacecraft
  - Objective is to improve the capability to mitigate or accommodate the effects of solar varying environments on spacecraft design and operations
  - Collect data in space to validate performance of new technologies and instruments for LWS science missions
  - Collect data in space to validate new & existing ground test protocols for the effects of solar variability on emerging technologies
  - Develop and validate engineering environment models, tools, & databases for spacecraft design & operations
    - Microelectronics
    - Detector (sensor) technologies
    - Materials (degradation and shielding properties)
    - Spacecraft charging

Spacecraft Charging

- **Characterization of Magnetospheric Spacecraft Charging Environments Using the LANL Magnetospheric Plasma Analyzer Data Set**
  - PI: V. Davis, SAIC
  - Co-Is: M. Thomson, LANL; M. Mandell and J. Hilton, SAIC
- **Environment Exposure Problem:**
  - Spacecraft charging due to diurnal variations in the plasma environment produces spacecraft anomalies and failures
  - Current models of the plasma environment are not correlated to spacecraft charging events
- **Engineering Tool or Model Product:**
  - Charging indices and fitting functions that can be used with models in NASA Spacecraft Charging Handbook and NASCAP2K
- **Flight Data**
  - LANL/geosynchronous data spanning 12 years measured using on-board Magnetospheric Plasma Analyzers
- **Applicability:** Spacecraft reliability for NASA, DoD, and commercial programs

Spacecraft Charging

- **Mining CRRES IDM Pulse and Environment Data**
  - PI: R. Frederickson, JPL
  - Co-Is: D. Brautigam, AFRL/Hanscom
- **Environment Exposure Problem:**
  - Spacecraft charging due to diurnal variations in the plasma environment produces spacecraft anomalies and failures
  - Current standards of the phenomena of the pulsing environment are orders of magnitude off
- **Engineering Tool or Model Product:**
  - Improved ground test fidelity of IESD pulsing by insulators
  - Better estimate of the electrical resistivity of the insulators
- **Flight Data**
  - CRRES spacecraft
- **Applicability:** Spacecraft reliability for NASA, DoD, and commercial programs

Spacecraft Charging

- **Electrostatic Return of Contaminants**
  - PI: R. Rantanen, ROR Enterprises
  - Co-Is: T. Gordon, Applied Sciences Technology
- **Environment Exposure Problem:**
  - Spacecraft charging due to the return of spacecraft emitted molecules that are ionized and attracted back to the spacecraft
  - No current model exists to predict this effect
- **Engineering Tool or Model Product:**
  - Development of a model capable of calculating the electrostatic return of contaminants
  - Final report
- **Flight Data**
  - N/A
- **Applicability:** Spacecraft reliability for NASA, DoD, and commercial programs

Microelectronics

- **Study of the Total Ionizing Dose Effects of High-Z Material Spot Shields on Field Programmable Gate Arrays (FPGA) Using the Flight Data From the Experiment Board on the Microelectronics and Photonics Testbed**
  - PI: Susan Crain, The Aerospace Corporation
  - Co-I: J. Mazur and M. Looper, The Aerospace Corporation
- **Environment Exposure Problem:**
  - FPGAs on the Microelectronics & Photonics Testbed (MPTB) with spot shielding show significantly more total ionizing dose degradation caused by protons and electrons than those with no spot shielding. Spot shielding is widely used to reduce dose on microelectronic components
  - The MPTB dose environment is dominated by the highly variable electron environment so secondary products of the shielding are suspected of causing higher doses
- **Engineering Tool or Model Product:**
  - Data analysis
- **Applicability:** Spacecraft avionics

Microelectronics

- **Analysis of CRRES Pulse Height Analyzer (PHA) Data for Low-Linear Energy Transfer (LET) Events**
  - PI: P. McNulty, Clemson University
- **Environment Exposure Problem:**
  - Single event upsets on microelectronics caused by trapped, galactic, and solar ions cause failures in microelectronics
  - Current interaction models do not include elastic interactions which are important for modern technologies
- **Engineering Tool or Model Product:**
  - COSMIC/CUPID codes will be updated to include elastic interactions for application to modern devices where these interactions have been shown to dominate. COSMIC/CUPID is used as a SEU rate prediction tool and as a research tool to understand device sensitivity/hardening
  - Validation will be accomplished with data from the CRRES PHA instrument
- **Flight Data**
  - CRRES (GTO orbit) PHA data spanning 14 months of solar maximum, including March 1991
- **Applicability:** Spacecraft and aircraft avionics, Ground effects on electronics

Microelectronics

- **Solar Variability, the Near-Earth Radiation Environment, and Transient Effects on Microelectronics - Mining Enhanced Low-Dose Rate Sensitivity (ELDERS) Data from the Microelectronics and Photonics Testbed (MPTB) Space Experiment**
  - PI: T. Turflinger, NAVSEA Crane
  - Partner: A. Campbell, NRL
- **Environment Exposure Problem:**
  - Enhanced low dose rate sensitivity (ELDRS) effect in linear bipolar integrated circuits means that devices degrade more at low space dose rates than at accelerated ground test rates
  - Current design guidelines recommend safety factors of 5x to 10x
- **Engineering Tool or Model Product:**
  - ELDRS data-set
- **Flight Data**
  - CRRES (GTO orbit) PHA data spanning 14 months of solar maximum, including March 1991
- **Applicability:** Spacecraft avionics

Microelectronics

- **Displacement Damage Effects in Solar Cells - Mining Damage Data From the Microelectronics and Photonics Testbed (MPTB) Space Experiment**
  - PI: R. Walters, NRL
  - Co-I: S. Messenger, SFA and T. Morton, OAI
- **Environment Exposure Problem:**
  - Solar cell degradation due to protons and electrons reduces mission lifetime unless margins are added. Lack of knowledge results in larger design margins than would be used if data were available
  - Current codes to calculate solar cell degradation are not adequate for state-of-the-art solar cells
- **Engineering Tool or Model Product:**
  - The Solar Array Verification and Analysis Tool (SAVANT) will be modified to predict on-orbit degradation of multi-junction solar cells. (SAVANT is available from NASA/GRC and OAI.)
  - SAVANT modifications will be validated using MPTB data
  - Effort will be initiated to extend SAVANT for thin-film solar cells
- **Flight Data**
  - MPTB
- **Applicability:** Spacecraft avionics

Detectors

- **Modeling Charge Collection in Detector Arrays**
  - PI: J. Pickel, PR&T
- **Environment Exposure Problem:**
  - Noise transients on optical sensors using focal plane arrays (FPAs) due to charged particles cannot be accurately predicted with current models because they do not account for the energy deposition by low energy particles and charge collection by drift-assisted diffusion
- **Engineering Tool or Model Product:**
  - Computer code of an improved model which includes drift assisted charge diffusion
  - Validation of code using unspecified flight data (SOHO/LASCO is available)
- **Applicability:** Instrument development for NASA and DoD, Broad application to charge collection problems associated with single event effects

Meteoroids and Orbital Debris

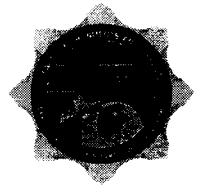
- **Origin of the Projectile Residues in the Largest LDEF Craters**
  - PI: F. Hörz, JSC
  - Co-I: D. Humes, LaRC
- **Environment Exposure Problem:**
  - Need to assess impact risks for future spacecraft
- **Engineering Tool or Model Product:**
  - Database on the composition and origin of the largest particles that impacted on the LDEF S0001 Experiment
  - Further classify the residues into man-made and natural impactors and to obtain the best population statistics for particles > 100um
- **Flight Data**
  - LDEF
- **Applicability:**
  - Spacecraft survivability in the LEO environment

Canceled

Meteoroids and Orbital Debris

- **Determination of Meteoroid Masses, Densities and Ballistic Coefficients Using Decelerations Obtained From Multi-Frequency Radar and Optical Data**
  - PI: R. Suggs, MSFC
  - Co-I: William Cooke, CSC; Peter Brown, LANL
- **Environment Exposure Problem:**
  - Need to assess impact risks for future spacecraft
  - Need to determine/estimate the densities of ablating meteoroids from measurements of meteoroid decelerations
- **Engineering Tool or Model Product:**
  - Database on meteoroid densities for determining similar bulk properties for gun tests
  - Database that will directly be implemented to developing meteoroid environment model development and evaluate future spacecraft effects due to impacts
- **Flight Data**
  - Data is taken from ALTAIR radar on the Kwajalein Missile Range
- **Applicability:**
  - Spacecraft environmental exposure and survivability

Ionizing Radiation

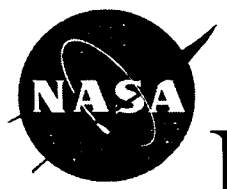


- **Non-ionizing Energy Loss (NIEL) Tool for Space Application**
  - PI: M. Xapsos, GSFC
  - Co-I: E. Burke, SFA, Inc., Insoo Jun, Caltech JPL
- **Environment Exposure Problem:**
  - NIEL due to galactic cosmic rays, solar particle events, and trapped protons and electrons causes degradation of solar cells, optoelectronic components, and CCD detectors
  - Current NIEL calculations for substrates other than silicon are limited, so degradation estimates for new technologies are not possible. Also, little work has been done for heavier ions which have higher damage factors
- **Engineering Tool or Model Product:**
  - User friendly computer program for calculating NIEL for space environments of concern
- **Applicability:**
  - Degradation effects on CCDs, particle and photon detectors, and solar cells

Ionizing Radiation

- **Improved Solar Particle Risk Assessment Tool**
  - PI: M. Xapsos, GSFC
  - Co-I: J. Shinn, J. Wilson, LaRC
- **Environment Exposure Problem:**
  - Mission planners need reliable risk assessment of extreme solar particle events (1-100 MeV)
  - The current statistical models apply only to cumulative, interplanetary proton fluences for solar maximum. Worst case events are needed for protons **and** heavy ions for the entire solar cycle throughout the magnetosphere
- **Engineering Tool or Model Product:**
  - Risk assessment tool (computer code) for spacecraft design and operations
- **Flight Data**
  - Particle data from IMP and GOES series of spacecraft
- **Applicability:**
  - Widely applicable to mission design, operations, and tactical launches

SEE



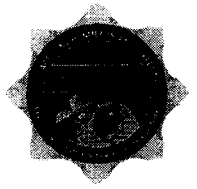
Neutral External Contamination

- **Satellite Contamination and Materials Outgassing Knowledgebase**
  - PI: B. Wood, BWACS Inc.
  - Co-I: D. Green, PSI
- **Environment Exposure Problem:**
  - Optical effects of surfaces due to contaminants
- **Engineering Tool or Model Product:**
  - Knowledgebase consisting of many flight experiments and ground-base tests utilizing testing of ASTME1559
  - Will add an additional 250 materials to the existing knowledgebase
- **Flight Data:**
  - Shuttle, MIR; mainly ASTME1559 ground test data
- **Applicability:**
  - Spacecraft reliability
- **Notes:**
  - Leveraging the existing "Knowledgebase" and its current infrastructure

Materials and Processing

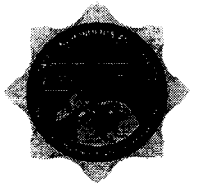
- **Improved Thermal Control Coating Development**
  - PI: Michael Donley, AFRL
  - Co-I: M. Deshpande, ITTRI
- **Environment Exposure Problem:**
  - Although design lifetime of Z-93P is 10-12 years, the end of life (EOL) performance of the current formulation (based on zinc oxide with a potassium silicate binder) degrades significantly from initial levels
  - Degradation causes the thermal management system to be designed much larger than needed for the desired performance level over the service life
- **Engineering Tool or Model Product:**
  - Will develop new thermal control coatings that have improved initial performance and significantly better EOL performance
- **Applicability:**
  - This work will produce a useful technology product for NASA and the satellite industry

Materials and Processing



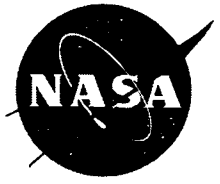
- **In-Situ Materials Properties Sensor**
  - PI: Donald Wilkes, AZ Technologies
  - Co-I: Zwiener/Crandall, AZ Technologies
- **Environment Exposure Problem:**
  - The natural and induced space environment can cause optical, mechanical and thermal damage to exposed surfaces, affecting the performance of critical spacecraft systems, including solar arrays, optical instruments, and thermal control systems
- **Engineering Tool or Model Product:**
  - Optical properties measurement sensor system that will have many uses for space experiments and ground base tests
  - The system will include capability for measuring solar absorptance, thermal emittance and optical scatter
- **Applicability:**
  - Space community is in need of in-situ measurement of optical properties.
  - The SEE community benefits by provision of health monitoring technology of space component

Spacecraft Charging



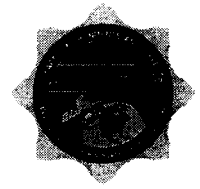
- **Electric Propulsion Interactions Code (EPIC): Integrated Guidelines and Tools for the Assessment of Electric Propulsion Impact on Spacecraft**
  - PI: M. Mandell, SAIC
  - Co-I: I. Mikellides, SAIC
- **Environment Exposure Problem:**
  - While high specific impulse of electric propulsion (EP) can be enabling, the impact of EP devices on spacecraft systems can be detrimental. Designers have little experience and no tools to aid in the design to integrate EP thrusters
- **Engineering Tool or Model Product:**
  - Integrated computer program including interactive guidelines for EP integration, both Ion and Hall Effect thruster plume models, and an engineering tool that models the interactions of these plumes with the 3-D spacecraft geometry
- **Applicability:**
  - This product will be applicable to commercial missions and NASA, including inter-planetary and planetary missions, deep space explorations and GEO telecommunications satellites

SEE



Spacecraft Charging

- **Measurement of Charge Storage Decay Time and Resistivity of Spacecraft Insulators.**
  - PI: J. R. Dennison, Utah State University
  - Co-I: A. Robb Frederickson, Caltech, JPL
- **Environment Exposure Problem:**
  - Resistivity values used when trying to determine how accumulated charge will distribute across a spacecraft as wrong, often by several orders of magnitude. This means the charge balance equation is wrong and cannot accurately model charge distribution
- **Engineering Tool or Model Product:**
  - Materials database of resistivity values and other charging parameters, engineering design guidelines and a charge storage decay time and resistivity test protocol
- **Applicability:**
  - Europa Orbiter, Solar Dynamics Observatory; any satellite flown in a severe electron environment



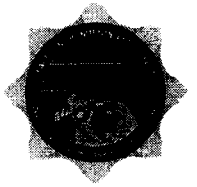
Other Current SEE Activities

- **NASCAP 2K**
  - Collaboration w/ AFRL/Hanscom
  - Being developed by SAIC (formally Maxwell Technologies)
  - A comprehensive update to the NASCAP charging analysis codes using the Air Force's new DynaPac charging algorithms. Three separate NASCAP codes (LEO, GEO, Polar) will now be merged into one comprehensive code
- **Sporadic Meteor Model**
  - Being developed by the University of Western Ontario and MSFC's Environments Group
  - Model is being developed by defining the sources (origins) of meteoroids, developing a prediction to match Earth observations, and extrapolation to the inner solar system
- **Ionizing Radiation Guidelines**
  - Being developed by SAIC, Individual Consultant and the SEE Program
  - To develop a design guideline (tutorial) for use by spacecraft designers (non-radiation experienced and 0-5 year experienced) and project managers; to aid in understanding the space radiation environment, its effects, and basic mitigation techniques
- **Electronic Properties of Materials Applicable to Spacecraft Charging Testing**
  - Being tested and developed by Utah State
  - Extension of the current three year effort for one year to test at least 8 more materials and input to existing databases and spacecraft charging models

Other Current SEE Activities

- **L2 Charged Particle Environment**
  - Being developed by MSFC's Environments Group
  - Assessment of "worst case" environment for tail (100 Re to 250 Re)
  - Semi-empirical engineering model of electrons and ions (few 100's of eV to ~ 1 MeV)
- **LEO Plasma Environment Variability**
  - Being developed by MSFC's Environments Group
  - Develop plasma variability database and model to specify statistical variations of plasma parameters (Ne, Te, Ni, Ti) for altitude range ~200-1000 km
  - Provide designers a range of values and not mean values (confidence levels)
- **Empirical Low Energy Ion Flux Model for the Terrestrial Magnetosphere**
  - Being developed by MSFC's Environments Group
  - Develop an empirical ion model of Earth's magnetosphere (50keV - 1MeV; 10Re -30Re)
- **Geospace Environment Implications for Spacecraft**
  - Being developed by AFRL
  - Development of new solar proxy and density databases for inclusion to the NASA MET model. Also, there is a separate development of a Data-driven Prediction of High Latitude Scintillations

Possible Future SEE Program Developments



- **Surveying and Examination of Eroded Returned Surfaces (SEERS)**
  - Performing evaluations and analysis of returned hardware from the Genesis spacecraft currently orbiting at L1 (FY04-FY06)
  - Hardware includes paints, materials, coatings, avionics, sensors/detectors, mechanisms
  - Participants to date: JPL, JSC, MSFC, GSFC, LaRC, GRC (possibly LANL in the future)
  - Future opportunities such as the Stardust missions (FY06-FY08)
- **JIMO/Prometheus Technology Development**
  - Coordination among JPL, MSFC, and GRC to develop technologies for the Prometheus Program
  - FY03: Activities include adding capability to EPIC to accept a 3D plume and initiated the development of test capability for high energy thrusters (physics characterization)
- **Space Technology Alliance**
  - Possible tri-agency sponsorship to address ionizing radiation model deficiencies (very preliminary stages)
  - Plans may include utilizing the SEE Program to implement
- **SEE Program NRA**
  - Possible NRA this fall for FY04 & FY05 technology activity sponsorship

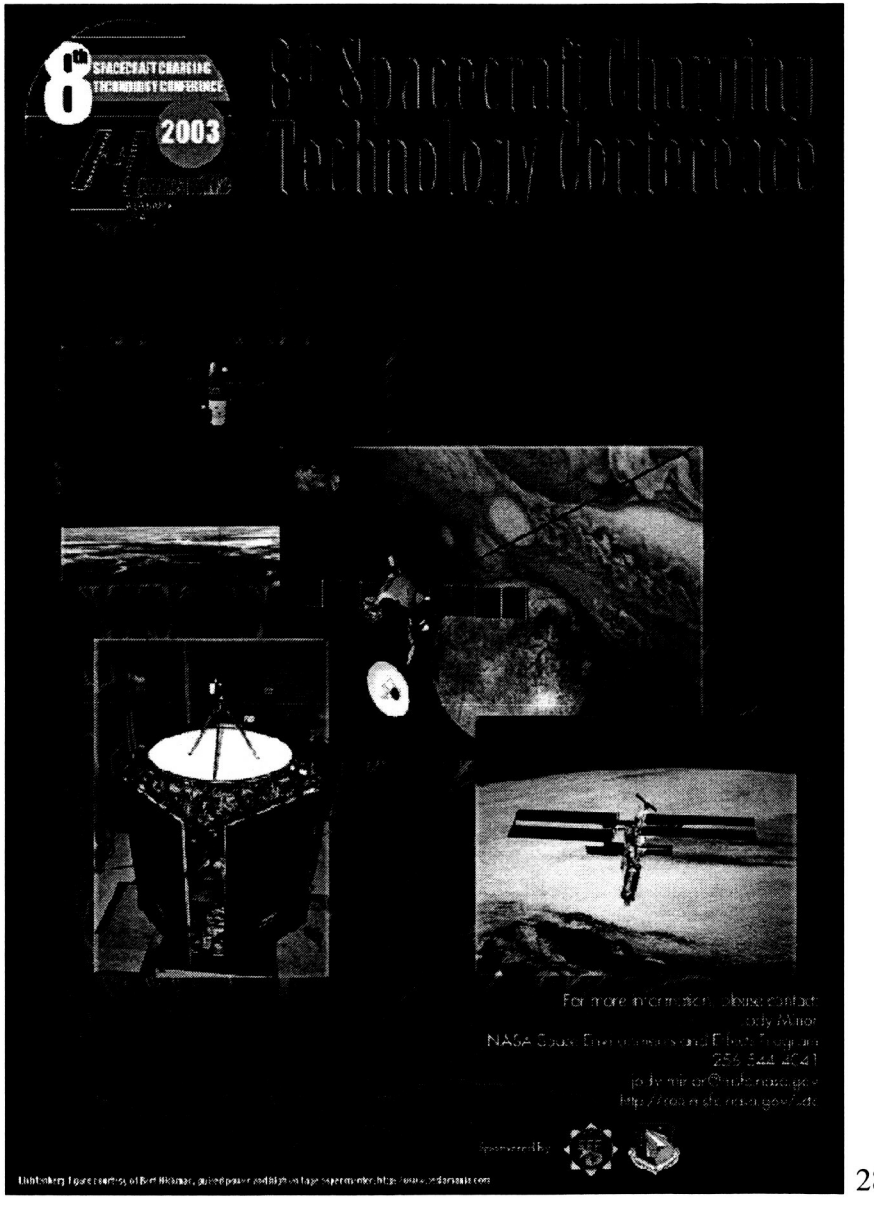
International Conference Host

8th SPACECRAFT CHARGING TECHNOLOGY CONFERENCE
2003
Huntsville
ALABAMA
USA

October 20 – 24 2003
Huntsville Marriott

Topics Include:

Models and Computer Simulations
Ground Testing Investigation & Techniques
On-Orbit Missions & Investigations
Environment Specifications
Plasma Propulsion
Materials Development



Closing Remarks

- This is a NASA technology development program which is customer-driven AND product-oriented
- There is a great interest in coordinating our activities with the entire Space Environments and Effects (SEE) community (i.e., other Gov't agencies, industries, and universities) to make maximum usage of new and existing SEE technologies
- The SEE Program is making a push to partner more with NASA missions to reduce their specific design uncertainties
- Our future role deals with inserting these new technologies into NASA, other government agencies, and commercial programs